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ABSTRACT

Of the dissertation for the degree of Doctor Philosophy

ORE-BEARING PALEOVOLCANIC STRUCTURES AND LOCAL PREDICTION OF GOLD MINERALIZATION IN THE TULALLAR ORE FIELD (LESSER CAUCASUS)

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INTRODUCTION

The relevance of work. Over the past decades since independence, there has been a radical rethinking of the geological characteristics and ore content of the Somkhito-Karabakh island-arc paleosystem. The productivity of Middle Jurassic volcanism, with which a number of endogenous ore deposits are spatially and genetically closely associated, has been thoroughly studied. The Upper Jurassic volcanics, with the exception of the Dashkesan ore region (M.-A. Kashkai, 1964), have been studied superficially. Meanwhile, as studies show, these formations are no less important components of the metallogeny of the region, since they control the location of many deposits of non-ferrous and precious metals (Buzlug-Bashkishlag group, Kapaz, etc.), which are undoubtedly of practical interest. In this regard, Tulallar is a specific research object. Taking into account the above, the magmatism of the Upper Jurassic complex is considered productive, and the areas of distribution of Kimmeridgian subvolcanic formations are promising for the search of Au-bearing sulphide mineralization. All this actualizes the problem being developed. The Tulallar promising area is located near the Chovdar mining and processing plant and has favourable prerequisites for its involvement in industrial development.

Purpose and main objectives of the research. The general final goal of the work implies the promotion of more specific tasks: 1) determination of the tectonic-metallogenic position of ore-bearing paleovolcanic structures and establishment of a connection between gold mineralization and extensive deep faults that control mineralization; 2) study of the characteristics of the composition and structure of the ore-bearing strata and determination of the position of mineralization in the context of productive formations; 3) to establish the nature of hydrothermal changes accompanying different types of ores, their facies and formational affiliation, to study the mineral and material composition of the ores and based on paragenetic analysis of minerals using the latest diagnostic techniques, to identify the main

features of the geological and physicochemical conditions of the localization of mineralization;

4) identification of the main patterns of mineralization placement, reflected in the structure of the deposit and, based on a generalization of the accumulated material, clarify its position in space and time;

5) identification and systematization of local forecasting factors, prospecting and evaluation criteria for Au mineralization and identification of promising areas within the area under consideration.

Research methodology and factual material. The dissertation is based on factual material collected and processed by the author during field and laboratory research during 2015-2023. Materials from geological exploration work of the National Geological Service of the MENR and "AzerGold" CJSC of the republic, in which the author was directly involved, were also used. Schematic geological maps of the most characteristic areas, numerous sections, horizontal plans of adits were compiled, cores of drill holes and etc. were reviewed and documented, the main features of the geochemical and metallogenic specialization of subvolcanic formations of Kimmeridgian volcanism were identified, and interpretation materials from space and aerial photographs of various scales were used. The structural and textural features of ores and the relationships between their constituent minerals have been studied using more than 300 samples, polished and transparent sections. 50 monomineral samples were taken under a binocular for various types of analysis. The study of fluid inclusions in minerals was carried out by the method of homogenization and decrepitation (45 determinations); to determine the origin of ore-bearing solutions, the sulphur isotope composition of the main sulphides was determined (25 determinations). The work used more than 3000 chemicals, atomic adsorption and spectral analyses for the main components, about 100 chemical and spectral analyses of group samples. The correlation between Au, Ag, Cu and other trace elements was determined using a mathematical statistical method using the "STAT" program. The main volume of analytical studies was carried out in the laboratories of İntertek (Australia), ALS Laboratuar

Hizmetleri LTD (Turkey), KIMS (Georgia), Geological Service of the MENR (Azerbaijan).

Main protected provisions. 1. A natural connection between mineralization and block structures confined to areas of latitudinal and sublatitudinal strike of regional faults has been established. 2. According to the nature of the section of ore-hosting formations, gold ore occurrences are localized in two stratigraphic ranges associated with silicic acid levels of a continuously differentiated formation: a) mainly in andesitic, andesidacite porphyrites and their tuffaceous formations of the Kimmeridgian (Tulallar) and b) in the Upper Bajocian rhyolites, rhyodacites (distant flanks of the Tulallar deposit - Sarychukhurbashi, Pant and other occurrences). 3. The deposit belongs to the group of volcanogenic hydrothermal epithermal, shallow and medium depths; the leading types of mineralization are gold-quartz-pyrite-chalcopyrite ore-bearing zones; gold-bearing secondary quartzites of the areal type of development play a lesser role.

The scientific novelty of the dissertation work is as follows: 1) the connection between gold-sulphide mineralization and block structures is substantiated; a number of zones favourable for the localization of this type of mineralization have been identified; 2) a spatial-structural connection between Kimmeridgian volcanism and gold mineralization has been established; 3) the relationship between the stages of mineralization, the zonality of metasomatite distribution and the connection of mineralization with ore-controlling and ore-localizing structures is shown; 4) a set of search criteria and signs of mineralization was developed, a 3D model of the ore-bearing zone was compiled, promising areas were predicted and a sequential scheme for their study.

The practical significance of the study is determined not only by the analysis of the placement of paleovolcanic structures and the local forecast of gold-sulphide mineralization, but also by the patterns of placement of endogenous ore accumulations established by the author; for the first time, zoning in the distribution of metasomatic rocks was revealed for the Tulallar deposit. The area, previously considered as an

object with gold mineralization, based on a whole complex of geological data, was identified as the upper level of the porphyry copper system. To clarify the correlations between Au, Ag, Cu and other trace elements, the work for the first time used a statistical method using the "STAT" program, and identified the most promising structures for the region, promising for gold-sulphide mineralization. They, which accompany different types of ores, can be used as a search criterion for identifying hidden deposits in areas adjacent to the ore field. The practical significance of the research results is also determined by the fact that the main provisions and conclusions contained in the dissertation can be used in metallogenic constructions, justifying the development strategy and strengthening the mineral resource base of the republic.

Approbation of work and publication. The main provisions of the defended work were repeatedly presented at geological seminars of the Department of Mineral Resources of Baku State University, at republican and international conferences. 19 scientific papers have been published on the topic of the dissertation (including 1 RSCI article and 2 SCOPUS-based articles), which reflect the main protected provisions. The work was carried out under the scientific supervision of Doctor of Earth Sciences, assistant professor Sh.F. Abdullayeva. In the process of writing it, the author used the advice and help of Academician V.M. Baba-zadeh, Doctors of Geological and Mineralogical Sciences, professors N.A. Imamverdiyev and B.G. Kalandarov, Advisor to the Chairman of "AzerGold" CJSC, Candidate of Geological and Mineralogical Sciences Sh.J. Musayev. The author expresses sincere gratitude to all of them. Particularly noteworthy is the help and support of geologists from "AzerGold" CJSC and the Tulallar geological exploration party of the National Geological Service of the MERC of the Republic, with whom the author had constant friendly contacts. The implementation of abroad research program would not have been possible without the kind support and attention provided by the Chairman of "AzerGold" CJSC Z.Z. Ibragimov, for which the author expresses his deep gratitude to him.

Structure and scope of work. The dissertation consists of an introduction, 5 chapters, a conclusion and recommendations, 14 tables, 49 figures, a bibliography, including 123 titles and contains 194 pages (the total volume of work excluding the bibliography, figures, tables is 201321 characters, including introduction – 7864 characters, chapter I - 58867 characters, chapter II - 67003 characters, chapter III - 18563 characters, chapter IV - 30782 characters, chapter V - 12758 characters, conclusions and recommendations - 5484 characters).

CHAPTER I. MAIN FEATURES OF THE GEOLOGICAL STRUCTURE, MAGMATISM AND METALLOGENY OF THE LESSER CAUCASUS

The Tulallar deposit, due to its geological position, is located in the transition zone between the Gekgel uplift and the Dashkesan trough[1]. Both structures are elongated in the latitudinal direction, according to the strike of the Somkhi-Karabakh island-arc paleosystem of the Lesser Caucasus, aimed at the dominant development of the earliest gold-copper sulphide and copper pyrite-barite-polymetallic, later (but also pre-orogenic) copper-porphyry and gold-sulphide-quartz; pre-exposed and orogenic skarn-magnetite, cobalt, mercury deposits and etc. Both in geological position and in petrological features and rock composition, these two structures - the Gekgel uplift and the Dashkesan trough - are very similar and associated with the formation of the Middle and Upper Jurassic volcano-plutonic association, which combines the products of successively differentiated volcanogenic and intrusive formations in within the mentioned tectonic structures[2]. The uplift, occupying the interfluve of Kyurakchay and Buzlugchay, is slightly elongated in the northwest direction and can be traced along the outcrops of Upper Bajocian rhyolites and rhyodacites in the near-crest part of the structure, from the Chiragdara deposit to lake Gekgel, well outlining its contours. Upper Jurassic volcanogenic formations appear

[1] Shikhalibeyli E.Sh. Geological structure and history of tectonic development of the eastern part of the Lesser Caucasus. Baku, Publishing house AN Azerbaijan. SSR, vol. 2 1966. p. 261

[2] Abdullayev R.N. Petrological and metallogenic features of Mesozoic volcanism in the Lesser Caucasus (Azerbaijan). Ed. AN Azerbaijan. SSR, 1965. p.138

intermittently along the northern foothills of the Lesser Caucasus in the Gekgel-Tauz strip. Within this strip, Upper Jurassic volcanism was most active in its north-western part. The products of their activity - paleovolcanoes and associated vent, extrusive and subvolcanic formations belong to the Kimmeridgian stage in age, are underlain by Bathonian and Callovian formations and are overlain by deposits of the Albian stage[3]. The structure of paleovolcanoes involves a thick pack of lava (upper part of the section) and pyroclastic (lower part of the section) rocks, corresponding in composition to basalts and basaltic andesites.

The studied area, in accordance with geological-tectonic conditions and patterns of development of magmatic processes, corresponds to the Alpine metallogenic era, which is characterized by a fairly widespread development of endogenous mineralization and, first of all, pyrites. Modern research is proposed within the Gekgel uplift and in the area of the Tulallar deposit, in particular, the volcano-tectonic depression.

Modern studies[4] suggest[5] in particular, a volcano-tectonic depression within the Gekgel uplift and in the area of the Tulallar deposit. The geological structure of the deposit and the position of gold-sulphide mineralization in it is considered in the context of the peculiarities of the block tectonics of the uplift. In each block, disturbances of smaller orders are developed in the upper structural floors. At the same time, in each individual block there are practically no significant differences in the types of magmatism and mineralization of the constituent volcanogens. Although the block structure of the uplift is confirmed by most of geologists (E. Shikhalibeyli and others), the connection with it of gold-sulphide mineralization has not yet been essentially considered.

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[3] Abdullayev R.N. Mesozoic volcanism in the northeastern part of the Lesser Caucasus. Baku, Publishing house AN Azerbaijan. SSR.1963. p.225

[4] Abdullayev R.N., Mustafayev G.V., Mustafayev M.A. et al., Mesozoic igneous formations of Azerbaijan and associated mineralization. Baku, Elm, 1988.p.157

[5] Gasanov G.M. Geological structure and patterns of placement of endogenous mineralization in the western part of the Somkhito-Agdam zone of the Lesser Caucasus. Author's dissertation ...cand. gm.sciences. Baku, 1981.p.29

CHAPTER II. BRIEF GEOLOGICAL CHARACTERISTICS OF THE TULALLAR DEPOSIT

2.1. Tectonic-metallogenic position and geological structure

Based on the results of interpretation of satellite images (SA) and aerial photographs (AFS) in combination with geological, geophysical and geochemical data, the area of the Tulallar field is considered as a rectilinear block with a white, yellowish-white, ocher-yellow phototone, presumably due to hydrothermal changes. Here, on photographs of all scales, steeply dipping faults are deciphered, feathering the main fault zone and limiting the volcano-tectonic structure. The ore field is located in the southern part of the Tulallar anticline of sublatitudinal strike, which, in the form of a second-order fold, complicates the northern wing of a large regional syncline. The syncline and folds of higher orders are composed of Jurassic and Cretaceous rocks, with the predominant development of Upper Bajocian and Kimmeridgian formations.

Intrusions common in the area are small stock-shaped bodies and dikes of two age groups - Oxfordian and Neocomian - and have a composition of andesites, andesidacites, diorites and etc. The structure of the ore field involves volcanic structures of the central type and volcanic domes, composed in the core part of moderately acidic and acidic volcanics: andesites, andesidacite and dacite porphyrites, rhyodacites and rhyolite porphyries. The volcano-tectonic depression hosting the Tulallar deposit is filled with volcanic rocks of the main productive level - Kimmeridgian dacites, andesidacites. They include facies of different formation conditions and types of occurrence - effusive and subvolcanic. All volcanics are characterized by a gently sloping (5-10°) bedding of layers with a general dip towards the center of the depression. The effusive facies proper combines lava, pyroclastic flows and synchronous volcanic-sedimentary deposits[2,3]. Subvolcanic and vent formations are considered by him as age analogues of nappes, having an identical composition and gradual transitions. The long axis of the depression is oriented in the near-latitudinal direction. In the south-western frame of the central

subsidence, outcrops of subvolcanic bodies of rhyolitic dacites have been established.

2.2. Geological location of gold-bearing areas

2.2.1. Tulallar site (promising gold-bearing area)

In the central part of the volcano-tectonic depression, the core is divided by the Tulallar fault into three blocks - Eastern, Central and Western, within which the same sections of the field are located. The tectonic contours of the structure (Main and Southern arc-like faults) are the boundary that determines the spatial distribution of vein-veined gold-sulphide mineralized zones[6]. Their localization occurs at the intersection points of the internal ring tectonic elements of the volcanic structure with the near-meridional faults cutting it, which are often mineralized[7]. To date, detailed geological exploration work has covered the Central Block. It is located between elevations of 1834.4 m and 1646.0 m and is well laid out on the surface at a distance of 2.5 km[8]. The structure of the area is determined by two systems of faults, mainly of the fault type: 1) fairly extensive faults of a northwest direction, consistent along the strike and dip, with a steep dip to the east, less often to the west (relatively ancient) and 2) ruptures, which are not extended in comparison with the first ones, have a north-eastern, less often near-latitudinal strike, dipping to the northwest and southeast. The presence of these discontinuities of different ages and different directions determined the local block structure of the site. These faults served as reservoirs for subvolcanic bodies and dikes of andesidacites, dacites, rhyodacites and the site as a whole, which indicates the decisive role of lithological and structural (fault) control in the placement of ore deposits. Crushed mineralized rocks containing Au from traces to 10-

[6] Ismayilova N.N. The role of structural factors in the placement of gold-sulfide mineralization in the Tulallar ore field (Lesser Caucasus) // News of Baku University (Natural Science Series). 2019, No. 2. p. 72-76

[7] Spatiotemporal and genetic relationships of volcanogenic gold-bearing sulfide deposits of island arc zones. M., Mining Journal, 2020, No. 8(2277). p. 23-32.

[8] Abdullayeva Sh.F., Baba-zadeh V.M., Imamverdiyev N.A., Ismayilova N.N. Epithermal gold-sulfide deposit Tulallar: main structural features, geological-structural position and patterns of mineralization (Lesser Caucasus, Azerbaijan. Moscow:Mining Journal, 2021, No. 9.p.53-60

15 g/t and above, Ag - from single to a few tens of g/t, Cu - from 0.05-0.1 to 1-1.5%, generally represent ore deposit, thickness from 20 to 70-80 m of near-meridional strike with steep dip angles. With the exception of metasomatic ores superimposed on andesitic and andesidacite bodies of the Kimmeridgian, supra-ore volcanics, as a rule, are not altered. More than 20 vein-veined gold-sulphide mineralized zones have been identified, traced along the strike and dip from several tens of meters to a few hundred meters. The zones are well recorded in geophysical fields by negative magnetism and increased apparent resistivity. In some places, there are bands that include a series of closely spaced ore zones and veins with a total thickness of up to 15-20 m. Despite the relatively large extent of ore zones, based on chemical and fire assay data from samples taken during mining and drilling, Au and associated metals are distributed very unevenly; there are numerous "barren" windows, bulges, constrictions, and apophyses. In this case, the increased content of Au is almost everywhere accompanied by an increased content of Ag, Cu, and in some places Zn. Here, rich gold-bearing mineralization, forming an ore column, is confined to the central area, the most broken by transverse faults, and is embedded in an aureole of weak scattered mineralization. The boundaries between commercial and non-commercial Au contents in a gold sulphide ore body are unclear and are determined from sampling data. The Au content, according to furrow sampling, reaches 5.42 g/t, Ag – 14.66 g/t. Single quartz-gold sulphide veins with a thickness of 0.03 to 0.25 m with very rich mineralization (Au - 60 g/t or more) can be traced here. The latter are localized mainly in the hanging side of the zones. Along strike they extend only 8-10 m. The composition of the veins, their structure and relative position indicate the duration and frequency of cracking and ore deposition. This is also evidenced by the complex intersections of ore-bearing faults and mineral associations, the presence of fracture systems of different ages carrying different mineralization, the presence of intermineralization brecciation, the predominance of veinlet ores over disseminated ores, the cementation of crushed minerals of an early generation by later segregations, the deformation

of crystals of initial generations and their erosion by subsequent ones, multi-stage hydrothermal-metasomatic changes and etc., occurring against the background of tectonomagmatic activity. The second ore column was discovered at a depth of 56 m, at a horizon of 1590.0 m. Here, an adit uncovered an ore zone with an average thickness of 38.5 m. Within the indicated thickness of the zone, the Au content ranges from a few hundred g/t to 10.17 g/t, however, within their limits there are areas enriched in the noble metal (up to 360 g/t Au). The thickest ore column with a high Au content has an orientation consistent with the zone and apparently plunges along the dip of the main fault to a depth of several tens of meters. The Eastern block is well studied only in conjunction with the Central block. The excavated mine workings show that the ore zone extends in a latitudinal direction, but the intensity of mineralization is decreasing. Here, with an activity of 31.7 m, the Au content is 0.81 g/t, Ag – 6.07 g/t. In the same section from the eastern selvage of the zone, a drilled well at a depth of 9-52 m discovered intensively limonitized, and in the lower parts with dense pyrite phenocrysts, secondary quartzites, where at a thickness of 43 m the Au content is 1.1 g/t, Ag - 6,9 g/t. The zone is then traced in geophysical fields. Heavy forest cover and thick modern sediments make it difficult to study the mineralized block to a sufficient extent. As in the Central Block, the main change in the host rocks for ore mineralization is silicification, sericitization and kaolinization of Kimmeridgian pyroclastic formations. A fairly dense network of faults, predominantly of a normal fault nature, extending in various directions, is also developed here. Among them, earlier ruptures of near-meridional and later ones of north-eastern, less often, near-latitudinal strike are distinguished. More than ten vein-veined gold sulphide mineralized zones have been identified at the site. Ore bodies are in most cases bounded on both sides by tectonic planes. In the *Western* block, the degree of mineralization of the vein-vein zones gradually decreases in the direction from the central part to the flanks of the ore bodies, their thickness is reduced, the angles of incidence change, apophyses and feathering vein zones appear and just above the level of the gorge of the river Meyranchay, at approximately the

1400-meter hypsometric mark, are hidden under Bathonian deposits and wedge out. In the area, the parts of the zone exposed to the day surface, were studied in two sections (ditches Nos. 69, 70). In the first, in two furrow samples with a thickness of 4 m from intensely chloritized, less limonitized Kimmeridgian tuffs with quartz veinlets, the Au content is 1.4 g/t, Ag - 7.2 g/t, and in the second, a zone with a thickness of 8.9 m, where at a thickness of 8 m the Au content is 1.2 g/t, Ag – 7.05 g/t.

The largest and the most structurally complex anomaly in the area of the deposit is superimposed on a zone of hydrothermally altered rocks with Au mineralization. The high efficiency of the VP was established, with the help of which a new zone of veinlet-disseminated mineralization was identified on the north-eastern flank of the area, at a depth of 50-70 m. Finally, 1-2 km to the NE of the deposit, under the Kimmeridgian volcanic-sedimentary rocks, an anomalous zone of NE orientation with an intensity of about 3-4% was identified, which is interpreted as a continuation of the Tulallar zone. These zones, extending in a north-northeast direction, lie to the southeast at steep angles. It is assumed that the mentioned zones at deeper horizons create a single anomalous zone. All this illustrates the geological significance of anomalous zones.

2.2.2. Sarychukhurbashi ore occurrence (promising area for gold)

The ore zones with gold-sulphide mineralization are not extensive, quite often they tap out along the strike and transform into weakly kaolinized tuffs. They contain increased contents of Au, Ag, Cu and Zn. The ore content of the lower horizons of the area is not clear. Its prospects are limited by the low contents of noble metals in the zones. Nevertheless, this area, which is an example of the close genetic relationship of mineralization with subvolcanic formations, like Tulallar, deserves further study. Ore sections of the vein zones are located on the far northern and northwestern flanks of the Chiragdara deposit.

2.2.3. Pant ore occurrence

Here, a crushing zone up to 30 m thick is associated with a system of gold-bearing vein subzones with phenocrysts of pyrite, less chalcopyrite and sphalerite, galena, faded ores and etc. In vein swellings, these minerals form small nests up to 0.2-0.3 m in diameter, traceable by 1.0-1.5 m. The zone, like the cover volcanics, is broken through by bodies of diorite porphyrites. The ore occurrence was studied by prospecting routes and surface mining.

CHAPTER III. MINERAL COMPOSITION OF ORES

3.1 Stages of mineralization and zoning of ore bodies

The mineral composition of the ore is essentially quartz, with a small amount of kaolinite, sericite, calcite, barite, oxides and hydroxides of Fe, Cu, Pb, and sulphides. The amount of Au and Ag containing minerals in ores varies widely - from thousandths of a percent to 0.09%. Au is part of chalcopyrite, pyrite, more complex tellurides, sulphosalts and native elements (Au, Ag). Quartz is the main vein mineral. The study of relationships and paragenetic association of minerals allows us to distinguish five stages of hypogene mineralization, separated by intra-ore tectonic movements[7]. Ore minerals are found in quartz in the form of inclusions, veinlets, nests, lenses, kidney-shaped deposits and etc. In total, these minerals make up no more than 5% of the total mass of ore.

The main useful component in ores, gold, is found in a finely dispersed and native state. In sulphides, it is dust-like and very fine in the main quartz mass, often finely dispersed (1-10 microns) in the form of chain-shaped, amoeba-shaped particles. Native gold is in typomorphism with chalcopyrite and pyrite, with subordinate importance of galena, sphalerite and fahlores. Under a microscope, it is observed in the form of drop-shaped and oval shapes, single and heaped accumulations of tiny grains of irregular shape, less often vein-like and lamellar, prismatic and isometric-crystalline deposits. Often, in association with hessite, iron hydroxides, near pyrite deposits with chalcopyrite, quartz and other minerals, intergrowths of gold grains are

observed in voids and cracks of low-temperature (chalcedony) quartz with a size of 0.02-0.03 mm.

According to many researchers[9,10], Au was introduced in the form of complex compounds and was sorbed by sulphides. A close correlation between Au and Ag, Cu has been revealed. The Au/Ag ratio is 1/4-5. Data from rational analysis of Au are given in the dissertation[11]. To study the correlation between Au, Ag and other impurity elements, the results of sample analyzes were used, processed by a mathematical statistical method using the «STAT»[12] program.

3.2. Material composition and technological characteristics of ores

Technological studies of ores were carried out (G. Veliyev, A. Akhmedov) at the Institute of Mineral Raw Materials of the MENR of the Republic based on the results of chemical, assay (Au, Ag) and emission spectral (İSP) analyzes of two laboratory technological samples. It has been established that the main industrially significant element in the ores is Au. Ag is also of interest for associated extraction. A positive factor is the minimal content of such harmful impurities as As, Sb, Ba in the material composition of ores. It is of interest to study the results of phase analysis of the forms of occurrence of native Au, including the size of grains and association

[9] Khodakovsky I.L. Characteristics of hydrothermal solutions according to the study of gas-liquid solutions in minerals. In: Mineralogy, thermometry and barometry. T.2. New methods and results of studying the parameters of ore formation. M.., Science, 1956.

[10] Lebedev V.A., Chugaev A.V., Parfenov A.V. Age and sources of substance of gold-sulfide mineralization of the Tonadonskoye deposit (Republic of North Ossetia-Alania, Greater Caucasus). Geology of ore deposits, 2018, T.60, No. 4. p.371-391.

[11] Akhmedov A.Z., Akhmedov A.M., Veliyev G.A. Material composition and technological features of ores of the Tulallar gold deposit (M. Caucasus) // Izv. NAS of Azerbaijan (Series of Earth Sciences). 2014, No. 3. p. 3-19.

[12] Baba-zade V.M., Imamverdiyev N.A., Ismayilova N.N., Abdullayeva Sh.F. Geochemical features of the Tulallar gold ore field//News of universities. North Caucasus region. 2021, no. 1. p.40-52.

with various minerals in the ores of the deposit. Au is characterized by relatively large free native particles with a clean surface, represented mainly by small thin (in the form of films) needle-shaped forms, most often in the intergranular spaces of chalcopyrite and pyrite. Along with the free form of Au, which predominates in oxidized ores, in all cases high rates of its extraction are achieved both by gravity and flotation. Gravity-hydrometallurgical technology for processing the ores of the Tulallar deposit is recommended.

3.3. Conditions of ore deposition and place of gold mineralization in the ore process

The sulphur isotopic composition of the sulphides is close to the meteorite standard: pyrite 1 contains δ^{34} S+0.3‰, with a spread from –0.4 to ±0.7‰. Pyrite 2 and sphalerite are enriched in the δ^{34}S isotope by an average of 2.5-2.0‰, respectively. At the stage of chalcopyrite formation, the content of the δ^{34}S isotope decreases to an average of +0.8 with variations from 2.6 to ±3.3‰. This clearly indicates a deep source of sulphur in the fluids and indicates the development of oxidation processes towards the end of sulphide formation and the deposition of chalcopyrite at a later stage in relation to pyrite and sphalerite, which is also confirmed by mineragraphic data. The homogenization temperatures of PV in quartz from veins with Au-sulphide mineralization (the beginning of the formation of quartz-pyrite (sulphur pyrite) association corresponds to T = 220-350°C with a decrease towards the end of the stage (the moment of formation of late pyrite) to less than 200°C. The period of decrepitation activity of minerals of the pyrite-sphalerite-chalcopyrite-galena association is extended and is characterized by two maxima - for sphalerite 220-310°C, for chalcopyrite - 210-320°C. The temperature of completion of the ore formation process, recorded by the homogenization of PV in barren quartz, is 150-200°C, and by post-ore carbonate veinlets – 125°C.

CHAPTER IV. REGULARITIES OF FORMATION AND PLACEMENT OF MINERALIZATION

4.1. Placement of mineralization in the context of productive formations

Gold mineralization is noted throughout the entire stratigraphic section of the Lesser Caucasus - from the Lower Jurassic to the Neogene inclusive, but the intensity of its manifestation in different structures is not the same and is determined mainly by the features of their tectonomagmatic development. Of primary importance in this case is the presence of thick units of pyroclastic rocks in essentially volcanogenic sections. In the section of formations of the Tulallar area, most of the gold ore occurrences are localized in andesites, andesidacite porphyrites and their tuffaceous formations (Kimmeridgian). On the far flanks of the deposit, in the area of the Chiragdara ore cluster, gold ore zones are associated with Upper Bajocian rhyolites and rhyodacites (Sarychuhurbashi, Pant, etc.)[13].

4.2. Geological and structural features of mineralization localization are caused by the existence of a volcano-tectonic depression in the area of the deposit. The main ore-controlling structure is the Tulallar-Chiragdara-Toganali deep fault. The ore-controlling influence of the fault is manifested in its close relationship with regional anticlines of the pan-caucasian strike and transverse faults that determine the block structure of the region. The connection of the ore zones with the Tulallar fault, the disjunctive faults of which are made by vein-veined gold-sulphide mineralization, is natural. Local ore-controlling factors, like regional ones, are based on the same nature: the dependence of the type of mineralization on its structural position and the composition of ores, the depth and composition of the host rocks, the change in material with strike, the concentration of mineralization in structural wedges can be traced in areas of junction of disturbances of different orientations and other[7,8,14].

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[13] Ismayilova N.N. New promising areas of the Tulallar ore field. News of Baku University (Natural Science Series). 2020, no. 4. p.122-129

[14] Savva N.E., Volkov A.V., Sidorov A.A., Kolova E.E., Murashov K.E. Epithermal Ag-Au deposit Primorskoye (North-East Russia): Geological structure, mineralogical and geochemical features and conditions of ore formation // Geology of ore deposits. T 61, No. 1, p. 52-74.

Ore-localizing structures are longitudinal, mostly steeply dipping (60-75°, sometimes 80-85°). Almost all gold-sulphide mineralized zones of the deposit are confined to the nodes of their interface with transverse faults. Gold ore zones are variable along the strike and dip - they wedge out, form breaks, merge and are again divided into separate veins - zones.

4.3. Forms, internal structure and conditions of occurrence of ore bodies

Based on morphological characteristics, vein bodies and veining zones are distinguished. The veins are predominantly of simple structure, have a consistent set of barren and ore minerals, have a steep dip, low thickness (from 0.15 to 1 m or more) with a length from 5-10 m to 100 m or more. Such veins are confined to single cracks. Complex bodies, as a rule, are confined to fractures of two strike systems (25-55° and 200-300°), and dip steeply (70-85°). Along with quartz, chalcedony, kaolinite, and sericite are often found in the veins. Veins are characterized by complex, linear, seemingly elongated zones, primary and secondary halos, the areas of which exceed those of ore bodies, which favors the use of geochemical prospecting methods. There are areas with the highest thickness and Au content (tens, rarely 100-200 or more g/t) - ore columns, especially in places of longitudinal bending of fracture zones, areas where fractures of different orientations meet, often extending to depth and corresponding to the root parts of ore bundles, which are associated with cutting zones of volcanic brecciation.

4.4. Near-ore metasomatic changes. Gold-bearing secondary quartzite metasomatites and primary ores

Ores and products of hydrothermal alteration, following each other in time, overlap each other in space[15,16]. In the central part of the

[15] Ismayilova N.N. Metasomatites and ores of the Tulallar gold deposit. Materials of the Republican Scientific Conference on "Actual problems of Geology" dedicated to the 98th anniversary of the birth of the national leader of the Azerbaijani people, Heydar Aliyev. Baku-2021

[16] Ismayilova N.N. On the issue of zoning of secondary quartzites and localization of gold-sulfide mineralization using the example of the Tulallar deposit (Lesser

brachyanticline, composed of effusive-pyroclastic formations of the Kimmeridgian, a monoquartzite zone of metosomatites is developed, along with the main rock-forming mineral - quartz, which has a cryptogranular structure and resembles chalcedony-like quartz, there are finely spotted accumulations of brownish opal with rutile needles; often sulphide aggregates cement fragments of fractured monoquartzites. Pyrite, chalcopyrite forms a thin chain in monoquartzites. As one moves away from the vent parts of the volcanic structure, monoquartzites are gradually replaced by a zone of quartz-sericite hydrothermalites. The volcanic structure of monoquartzites is gradually replaced by a zone of quartz-sericite hydrothermalites.

In this zone, the role of sulphide mineralization increases and gold appears. Sulphide aggregates, where pyrite sharply predominates, form dense, usually uneven dissemination in them, and accumulate in the form of lens-shaped jets with a length of tens of centimeters to a few meters with a thickness of banded jets up to 2-3 cm. The most frequent alternations of sulphide aggregates, usually confined to the boundaries of quartz-sericite bands, occur near the boundaries of quartz-sericite zones with monoquartzites. The latter, in turn, turn into propylites. A characteristic feature of the zoning of the fields of secondary quartzites and propylites under consideration is the wide variation in the scale of manifestation of different zones of the metasomatic column vertically and horizontally, depending on the structural features and facies composition of these structures. In volcanic edifices composed predominantly of highly permeable pyroclastic facies (vent and, especially, near-vent), the scale of horizontal zoning is 5-10 times greater than vertical. A striking example of this is the Tulallar volcanic edifice. The opposite picture is observed in the extrusive structure, composed of low-permeability lavas and lava breccias, in the presence of steeply oriented crushing zones. Here, the vertical extent of the hydrothermal-metasomatic zones of secondary quartzites sharply exceeds the horizontal. In this regard, it is natural that in the presence of

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volcanic structures with different ratios of high-low permeability facies, the ratio of vertical and horizontal zoning of secondary quartzites may be different. The considered options for the relationship between vertical and horizontal zoning are of great practical importance, first of all, for determining the levels of localization of mineralization, morphology and scale of ore deposits, since the latter in most cases are spatially and genetically related to the fields of development of secondary quartzites.

CHAPTER V. EVALUATION CRITERIA AND LOCAL FACTORS FOR PREDICTING MINERALIZATION

5.1. Selection of criteria and features

It is established that the location of gold ore areas is determined by the nature of the favorable section of the ore-bearing formations, the type of folded and discontinuous structures, direct and indirect signs of mineralization, which include: the presence of areas with an increased background of gold-sulphide mineralization; specific faults, local intersections of dikes of different ages, subvolcanic intrusions and their spatial relationship with mineralization; wall-ore changes in rocks associated with the acid stage of leaching, and above all silicification, pyritization, sericitization, kaolinization, silicification; primary halos of geochemical dispersion, confined to the most intensely altered areas, where the concentration of endogenous mineralization most often occurs. The main geochemical criteria are the concentration of gold and multiplicative groups, which characterize the intensity of the ore formation process, as well as the level of erosion of the aureole. Based on the nature of their application, search criteria and features are divided into three groups: 1) mass use, which does not require special work; 2) applicable only after mapping work has been completed; 3) used only upon receipt of the results of laboratory or special (geophysical, etc.) studies.

5.2. Forecast and localization of mineralization based on the results of geological exploration

The basis for local forecasting and assessment of mineralization is: 1) a detailed study of the most important ore-controlling factors - fault

structures that determine the possibility and preferred development of mineralization and 2) stratigraphic-lithological levels favorable for the placement of gold mineralization. Of no less importance are the mineralogical and geochemical factors that determine the specifics of the ore formation process, regional and local manifestations of metasomatites with superimposed fields of secondary quartzites, lithochemical criteria for primary and secondary geochemical gold halos and a wide range of mineralization indicator elements, identification of anomalies in geophysical fields presumably of ore nature. At the same time, information and statistical methods of data extraction were widely used.

5.3. The assessment of ore content and the prospects for identifying new ore occurrences was carried out using detailed geological and geophysical materials, geological and structural maps, mineralogy and geochemistry data, near-ore metasomatic changes, the composition and structure of ore-bearing zones.

The ore-controlling significance of faults is established due to the confinement of most occurrences to them, as well as on the basis of hydrothermal changes in rocks in fault zones. Ore zones are formed at the intersection of longitudinal ore-controlling structures (Tulallar reverse fault) with transverse ore-supplying faults of a submeridional direction. Folded forms, especially brachyanticlines, are important. In other words, the ore-bearing structures are of a combined nature. Metasomatic zoning identified along ore-controlling structures, as well as the distribution of indicator elements at depth, make it possible to determine erosion levels and, therefore, predict depth intervals for the opening of ore bodies. In the modern erosional section of the Tulallar deposit, it was discovered mainly in its upper (frontal) part; its ore zones are structurally interconnected and, in essence, represent branches of a single ore-magmatic bundle. The vertical extent of mineralization of the deposit (without taking into account the eroded parts) is estimated to be up to 300 m. Mining and drilling operations have studied the ore zones of the deposit along a dip of 100-150 m, which allows us to expect the identification of sufficiently large reserves of Au and complex Au-sulphide ores within its geological boundaries.

CONSLUSİON AND SUGGESTİON

1. The ore-bearing area is located at the junction of the Gekgel uplift and the Dashkesan trough. The main structural features of these structures are associated with the formation of a successively differentiated basalt-andesite-plagiorolite formation, with which the gabbro-diorite-granodiorite formation is spatially associated. A paragenetic connection between these formations and the possibility of the existence of a volcano-plutonic association are assumed. The ore-bearing rocks for the deposits are almost universally acidic and moderately acidic differentiates of the basalt-andesite-plagiorhyolite formation.

2. The deposit belongs to the pre-intrusive pre-porphyry volcanogenic hydrothermal epithermal of shallow and medium depths. Geological and geochemical studies indicate the presence of paragenetic connections between the development of hydrothermal processes and magmatism of the Kimmeridgian era. The same "set" of the main elements of mineralization in the deposit, as well as in magmatic formations, indicates a close connection between the processes of magma and ore formation. Structurally, mineralization is controlled by local volcano-tectonic structures. The morphostructural type of deposits is determined by a system of steeply dipping faults of the northwestern and northeastern (submeridional), less often sublatitudinal, striking in combination with radial subvolcanic disturbances. The nature of the structural preparation provided the morphological type of ore bodies - vein-veined with a subordinate meaning of lenticular. In the recumbent sides of ore zones, hydrothermally altered rocks containing veinlet-disseminated mineralization are usually intensively developed. A similar position is typical for a number of similar objects in adjacent territories of the island-arc paleosystem.

3. Analysis of discontinuities and fracture zones with gold-sulphide ore bodies allows us to conclude that within the Tulallar deposit they are oriented mainly in two directions: northwestern and northeastern (meridional). Gold-bearing zones and veins are localized in the position of such discontinuities of a northeastern, less often near-latitudinal strike, usually at the nodes of their intersection with tectonic

disturbances in a northwestern direction.

4. The main ore minerals of gold ore areas are chalcopyrite and pyrite; sphalerite, galena, fahlores and etc. are usually present in small quantities. In vein-vein mineralized zones, gold is mostly finely dispersed and microscopic, and the vast majority of it as an impurity is found in sulphides (mainly chalcopyrite and pyrite). The homogenization temperatures of FI in quartz from veins with gold-sulphide mineralization averaged 320° (with fluctuations ranging from 290 to 350°C). Productive ore formation occurred at temperatures of 320-180°C.

5. Ores and ore-altered rocks are interconnected in space and time and are products of a single mineral-forming process. The nature of the spatial distribution of low-temperature facies of secondary quartzites, mineral associations (sulphides, hematite, gold, tellurides), the absence of solid solution decomposition structures, the low iron content of sphalerites and the results of homogenization of gas-liquid inclusions, the explosion of mineralization and its connection with subvolcanic formations made it possible to substantiate the scheme of continuous and sequential development of metasomatic and ore-forming processes. Ore formation occurred under conditions of low and medium pressure and medium temperature.

6. The leading types of mineralization are vein-veined gold-bearing mineralized zones of varying thickness, superimposed on effusive-tuffaceous rocks. The gold content in ores varies from thousandths to 60 g/t, reaching 360 g/t and directly depends on the amount of sulphides (the main concentrators are chalcopyrite and pyrite) in the ore. Au/Ag ratio 1/4-5. Judging by the technological features of the selected technological samples, the latter are represented by two natural types of ores - oxidized and semi-oxidized, which are generally characteristic of gold-bearing sulphide deposits, which suggests the presence of sufficiently large reserves of primary sulphide ores at deeper horizons. The vertical extent of mineralization is about 300 m.

7. Local forecasting within specific ore-bearing areas was carried out using geological and geophysical materials, geological and structural maps, data on the material composition and mineralogical and geochemical characteristics of ores, which make it possible to identify

a certain relationship between the structural features of ore-bearing structures and the degree of concentration of endogenous mineralization in them. Local prospecting and evaluation criteria are divided into genetic groups (structural, lithologic-stratigraphic, mineralogical-geochemical), the relative significance of which was established empirically during field work and based on the analogy method.

In accordance with the degree of study and prospective assessment of the areas of the Tulallar ore field, the following are recommended as the main directions of work: a) detailed prospecting and survey work on a scale of 1: 10000 on the flanks of the ore field; b) searches for hidden mineralization in the northeastern part of the ore field, in the area of the wedge-shaped junction of reverse fault zones; c) additional study of the central part of the ore field to a depth of 500-600 m; d) detailed exploration of previously discovered gold-bearing quartz zones in the Sarychukhurbashi and Pant areas, which in their spatial distribution gravitate towards the Chiragdara ore cluster.

8. Based on the identified patterns of localization of mineralization, a predictive assessment of the prospects for ore content of objects of various scales has been developed. Direct and indirect signs of mineralization are outlined.

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